NEW SOUTH WALES.

DEPARTMENT OF MINES AND AGRICULTURE.

GEOLOGICAL SURVEY.

E. F. PITTMAN, A.R.S.M., Government Geologist.

MINERAL RESOURCES.

No. 11.

MOLYBDENUM.

BY

E. C. ANDREWS, B.A.,

GEOLOGICAL SURVEYOR.

SYDNEY: WILLIAM APPLEGATE GULLICK, GOVERNMENT PRINTER.

1906.

65418—(a) [2s.]

SACH'S MINE, KINGSGATE, 22 MILES EAST OF GLEN INNES.

THREE SPECIMENS—5 CWT., 6 CWT., AND 80 LB. RESPECTIVELY—TORN FROM ONE MASS OF MOLYBDENUM.

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Department of Mines,
Sydney, 1 February, 1906.

Sir,

I have the honor to submit for publication, a pamphlet, No. 11 of the Mineral Resources Series, on *Molybdenum*, by Mr. E. C. Andrews, B.A., Geological Surveyor.

The demand for Molybdenum has increased considerably of recent years in consequence of its successful use in the production of hard steel, and there has been a corresponding advance in the price paid for the ore.

Mr. Andrews' account of the latest known details of its mode of occurrence in New South Wales will, therefore, be welcomed by those interested in the search for new deposits of the Mineral.

I have the honor to be,

Sir,

Your obedient servant,

EDWARD F. PITTMAN,

Government Geologist.

The Hon. S. W. Moore, M.P.,

Minister for Mines and Agriculture.

MOLYBDENUM.*

MOLYBDENUM* is a white metal, with a specific gravity of 9. It is malleable, and is amenable to both welding and polishing operations. It is not, however, found in the native state. The most important of the ores of molybdenum is the sulphide known as molybdenite. An oxide also is known, viz., molybdic ochre.

Ores of Molybdenum.

(*a*) *Molybdenite.*—The crystals are hexagonal in form, tabular also, as short prisms horizontally striated. It occurs commonly in foliæ (leaves) masses and scales, also in a granular form. The cleavage is markedly basic—that is, the mineral admits very readily of separation into plates parallel to the base of the crystal form. The laminæ thus obtained are very flexible, but not elastic, *i.e.*, they may be bent readily in any given direction, but they will not spring back into their original position (as most micas do) when the pressure is released. The mineral is sectile. Its hardness is from 1 to 1·5—that is, it may be scratched readily with the finger-nail. Its specific gravity is such that the weight of a given volume is from 4·7 to 4·8 times that of an equal volume of water. The lustre is metallic; the colour is lead-grey, and it gives a bluish-grey streak on paper. It is opaque, and has a greasy feel.

The composition is molybdenum disulphide (written MoS_2)—*i.e.*, it contains 60 per cent., *by weight*, of molybdenum, and 40 per cent. of sulphur, when pure.

It has a striking resemblance to graphite (plumbago, or blacklead), both in softness and structure, but it produces a bluer mark on paper, and yields sulphur when burnt on charcoal. The author has found that many people confuse it with tinfoil.

(*b*) *Molybdite* has a composition of MoO_3—*i.e.*, in the smallest portion to which molybdite could be broken without altering its character there would be found 1 atom of molybdenum with 3 atoms of oxygen gas clinging to it.

It is a straw-yellow mineral, and occurs in capillary (hair-like) tufted forms; also as yellow earthy incrustations associated with the brilliant molybdenite.

(*c*) *Wulfenite*, or molybdate of lead, is another molybdenum mineral found in New South Wales. It is a rarer mineral than either molybdenite or molybdite. It occurs generally in squarish tables, also in massive form. Its hardness is from 2·75 to 3—*i.e.*, it is just too hard to be scratched with a finger-nail. (Ordinary pure limestone is about 3 in hardness.) It is a heavy mineral, being nearly 7·0 in specific gravity. It varies in colour from yellow to orange-yellow and red. It may also be dark dull-green, brown, or almost colourless. The streak is white. The mineral is brittle.

According to Rothwell's "Mineral Industry" for 1903, "To be marketable the ore must contain more than 45 per cent. molybdenum, and must be free from copper."

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* From *molybdos*, lead.

According to the same authority, "Molybdenum is used chiefly in the preparation of certain steels, for which purpose it is employed in the form of dark-blue powdered metal, containing from 95 to 99 per cent. Mo.; as ferro-molybdenum, with 50 to 55 per cent. Mo.; and as molybdenum-nickel, with 75 per cent. Mo. and 25 per cent. Ni. For tool steel from 2 to 4 per cent. Mo. is added; for other qualities, from 1 to 2 per cent., according to what is desired. The influence of molybdenum on steel is similar to that of tungsten, but it gives greater toughness, while molybdenum steel is more readily worked when hot, and stands hardening better than tungsten steel."

Preparation of Metallic Molybdenum.

"The first process employed commercially in the preparation of molybdenum consisted in the reduction by carbon of molybdate of lime, the latter being easily obtained pure. After the reduction the lime was separated from the metallic molybdenum by treatment with hydrochloric acid. The molybdenum thus prepared contained about 3 per cent. of carbon. This process was introduced in 1892 by Steinberg and Deutsch, at their chemical works at Grunan, near Berlin, where they were able to produce as much as 200 kg. of metal per day, and sell it at 1·90 dollar per kg., or 86·5 cents per lb. Since that time Moissan has prepared pure molybdenum by igniting ammonium molybdate, and reducing with carbon the molybdenum dioxide thereby obtained, the oxide and carbon being mixed in the proportion of 10 to 1, and the reaction affected in the electric furnace. Properly prepared, the metal can be obtained free from carbon, while metal contaminated with carbon can be refined by heating with molybdic oxide, at a temperature far below its point of fusion."

According to the same authority (Rothwell's Mineral Industry, 1901, p. 460), "The demand for molybdenite has largely increased within recent years, due to the property possessed by the metal of rendering chrome steel self-hardening." It is claimed that the hardening property can be imparted to chrome steel by the addition of one-half the quantity of molybdenum, as compared with tungsten.

Methods of Concentration.

It is well known that the perfect basal cleavage of molybdenum renders it non-amenable to methods of ordinary concentration. Experiments have been carried out in America with Canadian ore by Mr. J. Walker Wells, with a view to discovering a general method of treatment. One sample, consisting of 50 per cent. pyrrhotite, 18 per cent. pyrite, and 6·5 per cent. molybdenite in a setting of calcite, black mica, quartz, and pyroxene, was treated in a jaw-crusher; the larger pieces of molybdenite were separated by hand-picking; the remainder was then crushed in rolls set to 0·2-inch space, and screens were successively used with meshes from 0·3 to 0·05 inches. "The oversize from the screens, which consisted of molybdenite, mica, and rock, was treated on a Wilfley table, and yielded a commercial product. The Hartz jig was not adapted for concentrating this ore; but good results were obtained with the Wetherill magnetic separator, although, owing to the high current and slow speed necessary, it is doubtful if this separation can be done on a practical basis. Treatment by a modified form of the Elmore process was only partially successful,* as the large particles of molybdenite were not affected by the oil.

* Rothwell's Mineral Industry, 1902, pp 477, 478.

"A quartz and felspar sample, containing 2·5 per cent. molybdenite, was crushed and passed through various screens. The whole sample was then finely crushed and passed through a 0·05-inch screen, treated on a Wilfley table, the final process being by the oil process. According to Mr. Wells, no standard method can be adopted for concentrating molybdenite ores. Separate mill tests are required to determine the proper treatment in each case."

*Probable future Demand.**

It is now generally recognised that molybdenite and wolfram are both very valuable in the processes of hardening and toughening steel. There is little fear that while a *steady* production of these metals at a *reasonable* rate† be forthcoming, a substitute will be sought. Inasmuch, however, as the percentage of molybdenite and tungsten is small compared with the mass of steel employed, and, furthermore, as the steel used for the special purposes in which tungsten and molybdenite are employed is limited, these metals (to be payably mined) will stand very little increase of production, such as may reasonably be expected to result from a thorough prospecting of the peripheries of the acid New England granites.‡ At present it appears to be a competition between molybdenite and tungsten ores. Molybdenite brought a high price in New South Wales in 1903, which soon resulted in the prospecting for and finding of considerable supplies of wolfram and scheelite.

According to the Annual Report of the Department of Mines, New South Wales, 1904-5, p. 55, with the exception of one or two small parcels (such as, for example, tribute parties on Vickery's Blocks, Kingsgate), the bulk of the output of molybdenite was obtained from the mine held by Mr. V. Sachs, at Kingsgate (22 miles east of Glen Innes).

The quantity and value of molybdenite exported during the last four years are as follows:—

Year	Quantity. Tons.	Value. £
1902	15	1,841
1903	29	4,458
1904	25¼	2,726
1905	...	...

Hints to Prospectors.

In New England, and in New South Wales generally, molybdenite deposits occur at or near the junction of granite and the rock it has intruded (*i.e.*, thrust itself into). Nevertheless, at the very outset, let us understand that all of the granitic rocks in New England do not contain this mineral. The blue granite of Northern New England, foi example, which is very common about Tent Hill, Deepwater, Bolivia,

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* See also W. P. Cameron, B.A. Wolfram and molybdenite mining in Queensland.

† Molybdenite of fairly pure quality is worth about 1s. per lb. to the miner, yet molybdenum commands a *much* higher price. Similar remarks apply to wolfram and tungsten. As Queensland and New South Wales produce the bulk of both molybdenite and wolfram, it should pay a company to manufacture the metals *here*, and supply *at a reasonable rate*.

‡ Also to a thorough prospecting of the granites of the Herberton district. In Mr. Cameron's report, cited above, the general sequence of geological events is not given. It would be most important to know:—

1. Whether the molybdenite-bearing granites intrude the other rocks of the Herberton district.
2. Whether the granite peripheries are the main mineral repositories.
3. Whether (as in New England) the granites are sandy in nature, and whether replacement of country is pronounced.

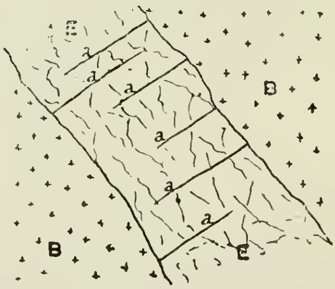
(See also later pages of this report.)

Wallangarra, and Tenterfield, contains none of this mineral. Neither does that great area of granite, magnificently porphyritic with very large pink felspars, occurring along the Drake-Tenterfield road, at Bungulla, the Rocky River, Wallangarra, Undercliffe, Wilson's Downfall Creek, and Moonbi (?). The molybdenite granites are coarse and fine sandy varieties, generally supporting a stunted vegetation of red gum, stringy-bark, white peppermint, blackbutt, dogwood, and oak trees. The rugged mountainous areas around Tenterfield, Bolivia, Deepwater, and east of Glen Innes are composed mostly of these mineral-bearing granites.

Search should, then, be made for molybdenite at the contacts of these coarse and fine sandstone-like granites with older rocks. The latter may be rocks of all descriptions, such as porphyries (Pheasant Creek), felsites and andesites (Emmaville locality), blue granite (Tent Hill and Bolivia), or slate (Kingsgate, Wallangarra, The Gulf, the Mole Table-land, Inverell district, Guy Fawkes, Deepwater, &c.). Of all these, the contact with slate is probably most productive.*

Having satisfied ourselves that the borders of the great sandy granite masses which are scattered over New England (and the associated coastal fall, such as Carrai, Nambucca, &c.) are the places well worth prospecting. Here it is necessary to sound a note of warning. In several instances the author has been taken to certain molybdenite "shows," and has seen at a glance that they are not worth exploiting. For example, around Tenterfield, Bolivia, and Wilson's Downfall, long tongues of the sandy granites are found running through the surrounding older rocks. These tongues (or walls) are at times as much as 100 or 200 yards in width.

Figure 1.



A = thin veins of quartz, ¼ inch to 1 inch wide, running at right angles to general trend of dyke.
B = "Blue granite" of Tenterfield. E = dyke or tongue (5 to 10 chains wide) of fine-grained sandy granite.

The accompanying figure illustrates such an occurrence near Tenterfield. The molybdenite occurs as flakes (like tinfoil) in tiny veins of quartz from a quarter of an inch to an inch in width, running normally to the strike of the granite dyke, which in turn traverses the blue granite of the locality. The molybdenite was evidently part and parcel of the granite dyke when it ran as a wall, in a liquid condition, through the country. On cooling, the granite dyke cracked in a direction at right angles to its length, and the molybdenite and quartz previously held in solution gradually found their way into these cracks. Or, again, as at

* Not only molybdenite, but bismuth, wolfram, tin, scheelite, gold, and monazite are found at these contacts. The molybdenite, however, is fond of associating with the very sandiest varieties only, so far as the author's knowledge goes.

Wilson's Downfall, Tenterfield, Bolivia, and other places, scales of molybdenite may be found scattered throughout the granite dykes *themselves*.

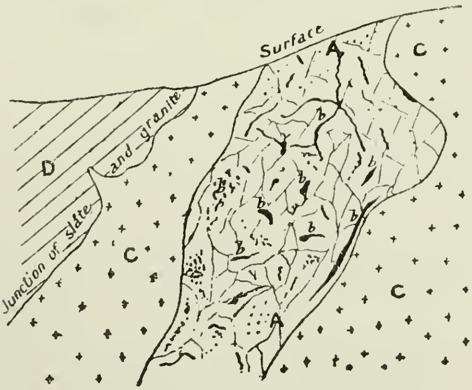
Dyke deposits of the types we have just been considering are not worth bothering about, as they have not undergone sufficient concentration to bring together payable masses of ore. Scientifically, of course, they are exceedingly interesting, as showing the origin of such ore deposits.*

Suppose, however, that around the borders of a *large* granite mass (say, from 3 to 10 miles across) we should find an irregularly circular or oval mass of white quartz, from 5 to 20 feet diameter, and showing flakes or nests of molybdenite (and bismuth) through it (see accompanying diagram), we are in a fortunate position, as in all likelihood we have found the upper portion of a so-called "pipe."

Figure 2.

(*a*) Plan of Pipe.

(*b*) Section of pipe showing probable appearance of (*a*) when quartz is followed down.



A = Quartz (pipe). *b* = Masses of molybdenite. C = Coarse or fine sandy granite
D = Slate or other associated rock.

* E. C. Andrews. Geology of New England. Pt. III. Genesis of the Ore Deposits. Records Geol. Survey N. S. Wales, 1905, VIII, pp. 22–45.

Here we have no defined fissure or reef such as one looks for when prospecting for gold and silver. Our only plan is now to follow the molybdenite-bearing quartz.* No one can tell you how the "pipe" will run, for no two "pipes" underlay in quite the same way. The "pipe" may broaden or become pinched, it may run vertically or bend over, it *may* keep on a general underlie; but it *generally* twists over and round like a bent corkscrew. Sometimes, however, molybdenite occurs in true veins or dykes (of quartz with felspar) in payable quantities. The prospector must use his own judgment as to whether a vein is worth exploiting.

Let us suppose he has an inch-wide fissure of tightly-set quartz, carrying 5 per cent. of molybdenite, and that molybdenite is worth £100 per ton for clean ore. To get a ton of quartz he will have to win 18½ square yards of reef—*i.e.*, with a shaft 6 feet long he will have to sink about 28 feet. The quartz contains some 2 cwt.† of molybdenite, worth about (at its present high price) £12. The ground will cost him from £1 10s. to £2 per foot to sink; therefore, to win £12 of molybdenite from such a reef he would expend about £45 in sinking. From this we see that a 5 per cent. reef of molybdenite in hard country would need to be 6 inches wide at least to pay, with molybdenite at £120 per ton.

A few remarks concerning the occurrence of quartz reefs generally will not here be out of place. The author has seen men jubilant at the discovery of reefs such as the one described above. Prospectors often contend that the narrow outcrop will "be sure to improve in depth" both in width and value. Now, this is against all experience, and the mass of experience is simply the basis of all mining geology.

Let us examine an outcrop with respect to its life at a depth, irrespective of its mineral values. If the reef is very narrow all along its course, and can be traced some 2 or 3 chains only along the surface, we may rest assured that *usually* this class of reef will pinch out below at little more than 100 feet. If the outcrop widens here and there, and can be traced along the surface for a mile or more, we may be sure such a reef will live to great depths, and that frequently it will widen out and "pinch" as it is traced downwards.

Again, if one finds molybdenite (or other mineral) scattered sparsely at intervals *only* along an otherwise barren vein of quartz, one may rest assured that such a line will be very patchy. Again, with few exceptions, one will find the outcrop, or the reef near the surface, to carry much *bigger* values than at depth.‡

Along many reefs shoots of ore occur, while the vein alongside is valueless. It will often be found, in such cases, that a cross-course or peculiar "bar" of country is associated with the rich shoot.

To understand these facts of experience the world over, one must have acquaintance with several important geological principles. To explain them we will attempt a brief summary of these ore deposits (molybdenite, &c.) of New England from the time they were formed at great depths below the earth's surface till they were exposed as we now see them at the surface by the ceaseless wearing away of the land by streams.

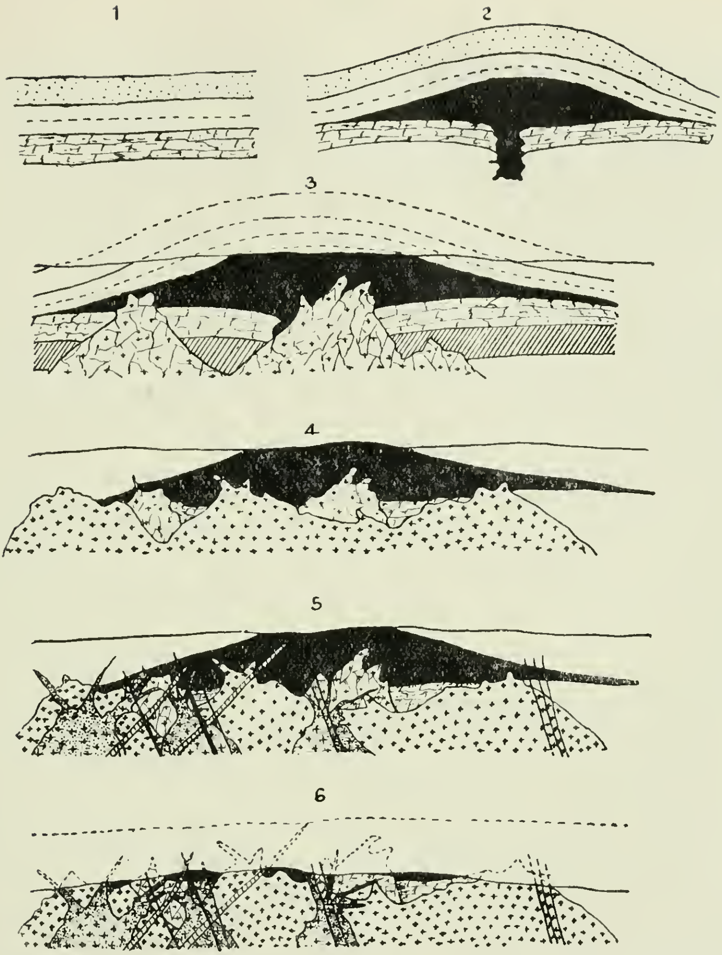
The various sketches shown on the following page explain themselves.

* It may be as well to add that wolfram, tin, and especially bismuth, may also occur in quartz "pipes." Sometimes gold "pipes" also are found as at Timbarra.

† Since molybdenite is almost twice as heavy as quartz.

‡ Some metals, like copper, give richer values at slight depths than at th surface. Gold, silver, tin, and many other metals, however, yield their best values at and ar the surface.

Figure 3.



Diagrams illustrating History of Granites in Northern New England.

1. Old stratified rocks (slates, sandstones, and volcanic rocks).
2. "Blue granite" of Tenterfield, &c., rising along a "pipe" or chimney, and forcing itself between layers of upper rocks, thus causing huge dome-shaped mountains.
3. (*a*) Wearing away of the mountains. The dark horizontal line represents surface induced by streams. The dotted lines represent the land mass worn away.
   (*b*) Intrusion of "blue granite" and stratified rocks by the granite porphyry of Tenterfield.
4. Intrusion of "blue granite" and granite porphyry by coarse acid granites. These granites contained some of the tin, wolfram, and other deposits.
5. (*a*) Intrusions of foregoing rocks by fine-grained "sandy" granites. It was this age which marked so many of the molybdenite, tin, bismuth, and associated deposits of New England.
   (*b*) Intrusion of foregoing rocks by rhyolite and porphyry dykes.
   (*c*) Intrusion of all the foregoing by diorite and allied dykes. These ushered in many of the Hillgrove, Drake, and Rivertree mineral deposits.
6. Wonderful removal of mountains by streams since granite intrusions. Dark horizontal line represents present land surface. The succession of events, was as follows :—
   (*a*) Great elevations.
   (*b*) Exposure of granites.
   (*c*) Formation of plains in granites.

Dotted lines show land mass worn away by streams.

In 1 is shown a series of slates and related rocks which, ages ago, were laid down in a sea covering almost the whole of the area now known as New England.

At 2 we see the way in which the blue granite was most probably forced into the upper portions of the earth's mass—*i.e.*, the crust or portion some little distance below the surface. In all probability the molten mass rose along a kind of chimney or pipe. Upon approaching the earth's surface it forced two or more layers of rock apart, squeezing itself between them, and causing the rock-layers above it to swell like a balloon and form a series of great dome-shaped mountains at the surface.*

Some time after this† the land was crumpled up to form great mountain ranges. The streams afterwards swept these high land masses into a shallow sea to make the enormous areas of slates, pudding-stones (conglomerates), &c., one sees at Drake, Rivertree, Boorook, Sandy Hills, and Tooloom. This wearing away is seen at 3, the portion removed being indicated by dotted lines above the later land surface.

Then a great mass of very coarse granite‡ rose gradually through both slate and blue granite, as shown at 4. Apparently the mass worked its way upward much as a miner rises from a lower to a higher mine-level by the process known as "overhead stoping"—*i.e.*, it rose along joints and wrenched off huge blocks from the sides and roof, letting the masses so broken fall into its fluid mass, and itself rising to take their places.

Look at the sketches now, and you will observe that the granite masses are shown as not reaching the surface.

All leading geologists, chemists, and physicists are agreed that a rock, such as granite of ordinarily coarse nature, *could not have been formed at the earth's surface*. Both the appearance of the granite and the changes it has wrought in the rocks through which it has forced its way show that it has cooled from a once fluid state *at great depths*—say, from 5,000 to 20,000 feet—below the present surface. Therefore, when one traverses the far-stretching granite plains which now characterise our New England, he may feel confident that the place he beholds was at one time buried under masses of rock thousands of feet in thickness! Some wonderful force or forces, then, must have, at some later period, stripped off the overlying mountain masses. To this we will devote a later paragraph.

To return to the granite. It must be remembered that this great intrusion did not contain mineral deposits of commercial value.

Soon after its appearance, geologically speaking, several other masses of granite (some coarse, others fine like *sandstones*) of different ages rose through slate, blue granite, and coarse porphyritic granite alike. These were sandy rocks, and, with a few exceptions,§ of little or no use for cultivation purposes. Thoroughly mixed up with these liquid masses were immense quantities of water. While the granites were in the liquid condition, the water could not be distinguished from the general mass, since it was intimately related to it much as water when mixed with flour to make dough cannot be distinguished as water, since it is now part and

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* It may, however, have forced itself more evenly between the rock layers, and caused a great table topped mountain, with sloping borders, at the surface.

† It is very probable, however, that the "Blue Granite" was thrust into the rocks described in this paragraph. Its *exact* age is not known.

‡ It must be remembered that these diagrams merely illustrate how, in one small area (about 50 miles across), the granites succeeded one another, and that only approximately. For more detailed accounts, see Reports on the Geology of New England, Parts II, III, and IV, by the author. Records Geol. Survey N. S. Wales, 1905, VIII.

§ Exceptions are (1) the granite around Wilson's Downfall itself, (2) the granites close to Glen Innes (3) the granite at Hillgrove township.

parcel of the dough or bread. Or, again, our bodies are three parts water out of four, yet all we see is flesh, blood, bones, and skin. Similarly for the molten granite. But on cooling the various minerals separated out as mica, felspar, quartz, &c., and tended to leave the water behind. Unless we think carefully about this, we will fail to grasp its significance. This water, left over as it were from the solidifying granites, was under *an enormous pressure* (being weighted down, probably, by miles of rock), and, as it was, indeed, a part of the granite, it must have been *as hot as the cooling rock itself*. Think now of the innumerable droplets moving about in the cooling rock ever gathering into larger masses, since like tends to congregate to like. In the rocks were, also, various powerful solvents such as hydrochloric and hydrofluoric acids. Tiny particles of tin, molybdenum, tungsten, gold, silver, iron, and other metals were (as we have seen) scattered all through the cooling mass, and the intensely hot waters* charged with acids gliding about in the plastic rock in their attempts to move away and get together would dissolve the metalliferous particles as easily as ordinary water can hold sugar in solution. In course of time the heated waters moved away to the cooler rocks surrounding them. Here, also, the ground had cracked, because the granites in cooling contracted, and the line of granite and older rock contact was naturally a weak one. Into these cracks the mineralised waters found their way, and deposited the molybdenite, &c., as veins and "pipes." In many other cases also the heated metalliferous waters and gases replaced the granites themselves with ore bodies.

The molybdenite deposits may occur in either coarse or fine-grained granites, yet they are almost, without exception, closely associated with dykes and masses of the "sandstone" granite traversing the coarser rock. This "sandstone" granite, in all likelihood, was the parent of the ore.

But as yet not a sign of these deposits could be seen on the surface during the period we have been considering.

However, several times a great force caused New England to rise bodily for hundreds of feet. Each time that the land rose, *the streams* cut the elevated surface away almost to sea-level. Below that they could not cut, as we know by an examination of present stream channels. In this way the granites were gradually unearthed and saw the light of day. As the granites were uncovered, so also were their *associated reefs* exposed. For millions of years the streams have been wearing away the reefs and sweeping much of their contents into the neighbouring watercourses. An almost inconceivable number of these molybdenite, tin, and other deposits must thus have swept away altogether. (See below dotted lines in Fig. 3 (6).)

Ages ago the old watercourses of New England were filled with the minerals washed from such reefs as the land was being worn down. Then came basalt floods, which deluged New England and buried these deposits. *Since then the present lower plateau of New England has been cut by the streams*. The magnificent gorges of the coastal streams have been cut at a still later period. The old buried watercourses we now know as the "deep leads." These old buried "tin" and "gold" leads of New England show, then, the enormous time that the reefs of New England have been exposed, and also the wonderful losses they have suffered. Some were being exposed as the bottom parts of others were being taken away.† *Thus the outcrops we see to-day are merely samples of the reefs*

* Very possibly these waters were so hot that they could exist only, in great measure, as *gases*.
† The "Little" Reef of Hillgrove is an instance. At the 12th level the *tops* of fresh reefs have been found.

which must have been scattered all round the granite domes. Is it possible, then, seeing how the reefs have been exposed, that the present surface of New England, over plains, high mountains, and the sides of deep gorges alike, should have been chosen by the streams so as to allow the *least valuable and narrowest* portions only of the reefs to outcrop on the present surface?

The answer is decidedly—No. Hundreds of reefs have been entirely swept away; we see here the top of one reef exposed; here another is almost worn away; while others are exposed midway between their former outcrops and lowest levels. The only legitimate inference is, that the present outcrop of a reef is an average sample of its width, &c., at a depth.

Here, then, we have the reason for our foregoing statements concerning reefs. The most important thing we should have learned is, that *below the outcrop or surface a reef containing insoluble metals cannot be expected to improve* either in width or value with depth.*

LOCALITIES AND DESCRIPTION OF WORKINGS IN NEW SOUTH WALES.

In the following notes, many localities at which molybdenite occurs in New South Wales are quoted from "The Mineral Resources of New South Wales," by Mr. E. F. Pittman.

Attunga.—Associated with copper sulphides in copper mine. (Quoted from G. W. Card.)

Bolivia, County Clive.—Molybdenite (Liversidge). (Quoted from E. F. Pittman.)

Bolivia, 2 miles south-east of Railway Station.—Occurrence: Molybdenite in quartz, as a segregation from coarse sandy granite near contact with blue granite. The attention of the author was drawn to this by Mr. Joseph Stevens.

Bolivia, 8 miles west of Bolivia Railway Station, along the track to Pye's Creek Silver Mines.—Occurrence: Molybdenite as flakes and scales in quartz and quartzose pegmatite. Wolfram also occurs sparingly in places. Molybdenite less than 1 per cent. The country is a coarse sandy granite, near contact with older and much more basic igneous rocks.

The gangue is remarkable. It is mostly quartz, but shows varying quantities of crystallised pink felspars. The felspathic constituent at times does not exceed 1 per cent, but frequently reaches as much as 10 per cent. of the mass; it rarely attains to 30 per cent., occurring as well-defined crystals set in a quartz paste. In one or two cases the quartz is observed passing into an eurite ("sandstone" granite).

The country is hard, and the percentage of molybdenite contained (not exceeding 1 per cent.) does not warrant its further exploitation at the present.

Shown to the author in 1901 by Messrs. Meredith Brothers.

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* Those who are interested in this question should consult the report by the author on The Drake Gold and Copper Field, Mineral Resources, N.S. Wales (*in litt.*)

Brewongle, 9 miles east of Bathurst.—Molybdenite in flakes, set in white quartz. A segregation in the Bathurst granite. The occurrence is of no commercial value.

This deposit was shown to the author in 1896, by the late William Pascoe, of Bathurst.

Bow Creek, Deepwater, 6 miles east of Deepwater.—Occurrence: A pipe-like formation of quartz, with molybdenite crystals at the junction of acid granite and older folded slates. Dykes and segregations of "sandstone" granite are included in the coarse rock.

In this locality several irregularly-shaped masses of quartz, containing numerous molybdenite crystals, have been followed down a few feet, but, owing to ignorance of the character of mineral "pipes," the prospectors spent money needlessly. The molybdenite has not yet "cut-out" in the bottom of the trial holes, and if the percentage of molybdenite found was payable, then these occurrences are worth further exploiting. The only advice to be given to intending prospectors is to follow the mineral. So long as any molybdenite-bearing quartz is showing, either on the sides or the bottom of the workings, so long is there a chance of the quartz making into a "pipe." The original prospectors, however, were possessed of the idea that, to be of any use, the occurrence must turn into a defined reef; hence their disappointment.

The crystals of molybdenite found here were very beautiful, being in form of hexagons, built up in rosettes and roulettes.

The occurrence was shown to the author in 1902, by Mr. G. V. Collins.

Broken Hill.—Wulfenite, with silver and lead ores. (Quoted from E. F. Pittman.)

Bullin Flat, near Goulburn.—Molybdenite (Liversidge). (Quoted from E. F. Pittman.)

Carcoar.—(Quoted from G. W. Card.)

Capertee, County Hunter.—Molybdenite (Liversidge). (Quoted from E. F. Pittman.)

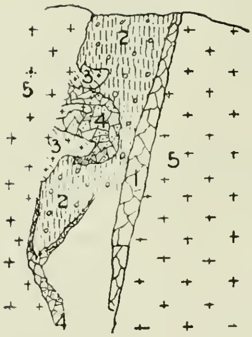
Cleveland Bay.—Molybdenite (Liversidge). (Quoted from E. F. Pittman.)

Ding Dong, 10 miles east of Deepwater.—Molybdenite in quartz, associated with wolfram, mispickel, and bismuth ores. (Quoted from E. F. Pittman.)

This is associated with, or close to, large deposits of greisen at and near the junction of a coarse acid granite and slates. (E.C.A.)

The Coronation Mine, 13 miles east of Deepwater.—Occurrence: Felspar dyke containing a little quartz, and passing gradually into a quartz vein containing about 20 per cent. of crystallised pink felspar. The portion of the vein composed mostly of large massive felspar (pink) has a width of 2 ft. 6 in., and is the molybdenite-bearing portion of vein. Strike of vein is North 5 degrees East, with a dip of 80 degrees. The molybdenite-bearing portion is about 150 feet in length. Alongside the felspar a small vein of quartz some 4 inches wide occurs carrying molybdenite.

Figure 4.



Coronation Mine.

1. Quartz vein.
2. Molybdenite crystals in crystalline felspar.
3. Granite veins or segregations.
4. Quartz, with small percentage of felspar.
5. Granite country.

A shaft 32 feet deep has been sunk on the reef. The country is a coarse acid granite, and closely associated with the reef is a huge barren quartz vein. The occurrence was shown to the author in 1902, by Mr. F. W. Thompson, of Deepwater.

Glen Creek, County Gough.—Molybdenite (Liversidge). (Quoted from E. F. Pittman.)

Goodrich Mine, County Gordon.—Molybdenite (Liversidge). Intimately associated with copper pyrites (G. W Card). (Quoted from E. F. Pittman.)

Guy Fawkes, Parish Cunnawarra, County Clarke, 4 miles from Guy Fawkes Post Office.—Molybdenite flakes in quartz occurring in acid granite.

Hogue's Creek, 12 miles north of Glen Innes.—Molybdenite in large quartz lode, associated with wolfram, cassiterite, and bismuth (Porter). (Quoted from E. F. Pittman.)

This is also associated with greisenization near contact of coarse acid granites with older felsites and breccias. (E.C.A.)

*Jingera Mineral Proprietary Mines.**—"These mines are situated at Whipstick (near Wyndham), about 14 miles to the west of Panbula, and are at the present time producing nearly all the bismuth raised in New South Wales. In their character and mode of occurrence the deposits are very similar to those of Kingsgate and Pheasant Creek, from which they are distant about 500 miles. They consist of more or less cylindrical pipe-veins, which have a very irregular course and inclination, and which *intersect granite rocks in proximity to their junction with slate.*† The filling of the 'pipes,' however, instead of consisting entirely of quartz, as is the case at Kingsgate, is composed of a coarsely crystalline admixture of felspar and quartz, with a little mica and occasional bunches of garnet rock. At least six of these 'pipes' have been found, and they are all situated in proximity to a dyke (about 4 or 5 feet wide) of trachyte, which intersects the granite. The maximum diameter of the 'pipes' is about 15 or 20 feet. . . . The minerals . . . are native bismuth, sulphide of bismuth, carbonate and trioxide of bismuth, and molybdenite. No wolfram has been found in these deposits. . . . ."

* E. F. Pittman. The Mineral Resources of New South Wales, pp. 261, 262.
† The *italics* are mine (E.C.A.).

Kempsey (near), County of Dudley.—Molybdenite (Liversidge). (Quoted from E. F. Pittman.)

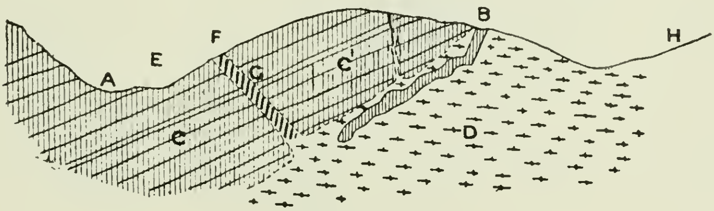
Kiandra, County of Wallace.—Molybdenite in quartz (Liversidge) (Quoted from E. F. Pittman.)

*Kingsgate.**—This district is noted for the great number of "pipes," or long bent cylindrical masses of quartz containing molybdenite and bismuth, which occur at and close to the junction of a coarse acid granite and older folded and altered slates. The accompanying map, taken from Mr. E. F. Pittman's "Mineral Resources of New South Wales," illustrates some of the very numerous "pipes" found in this locality.

As a type of these deposits, Sach's Mine, the great molybdenite producer, is chosen for description. Every facility for inspection of mine and machinery, &c., was afforded, both by Mr. V. Sachs, and by Mr. D. Munro in Mr. Sach's absence.

The "pipe," or cylinder, as is shown by the accompanying plan and section, is of twisted form, not having its axis in one plane, and occurs

Figure 6.



Section from Sach's Molybdenite Mine to Yarrow Creek. The longitudinal section of the pipe is projected into one plane for simplicity.

Scale—1″=2 chains, vert. and horiz.

A. Yarrow Creek, 2,860 feet above sea-level.
B. Pipe 245 feet along underlay.
C. Slate, dip. N.E. at about 50°.
C[1]. Slate, much hydrated and silicified.
D. Coarse acid granite.
E. Concentrating plant.
F. Ore pass.
G. Banded miarolitic dyke, showing much tourmaline and pegmatite.
H. Site of other pipes.

at the very junction of the granite and intruded slate. It is very variable in width, changing suddenly from 8 to 20, or even 25 feet in diameter; the latter measurement is, however, exceptional. Therefore, it will be readily understood that, at no one time, can there be any large body of ore in sight, since the very following down of the ore body for shaft-sinking purposes involves the removal of almost the whole of the ore body. Again, no adit levels could be run into the hill to prove the mine at a depth much below the present bottom workings, owing to the tortuous course pursued by the "pipe." An inspection of the section,

* See also E. F. Pittman, Mineral Resources N. S. Wales, pp. 257-261 with plate. C. S. Wilkinson, Ann Report Dept. Mines for 1883, pp. 153-155.

however, shows how a drift, run in just above the level of Yarrow Creek, and started near the site of the present concentrating plant, would facilitate the winning of the ore.

From these facts it will be seen that the only means of exploiting such a deposit is by following it down carefully.

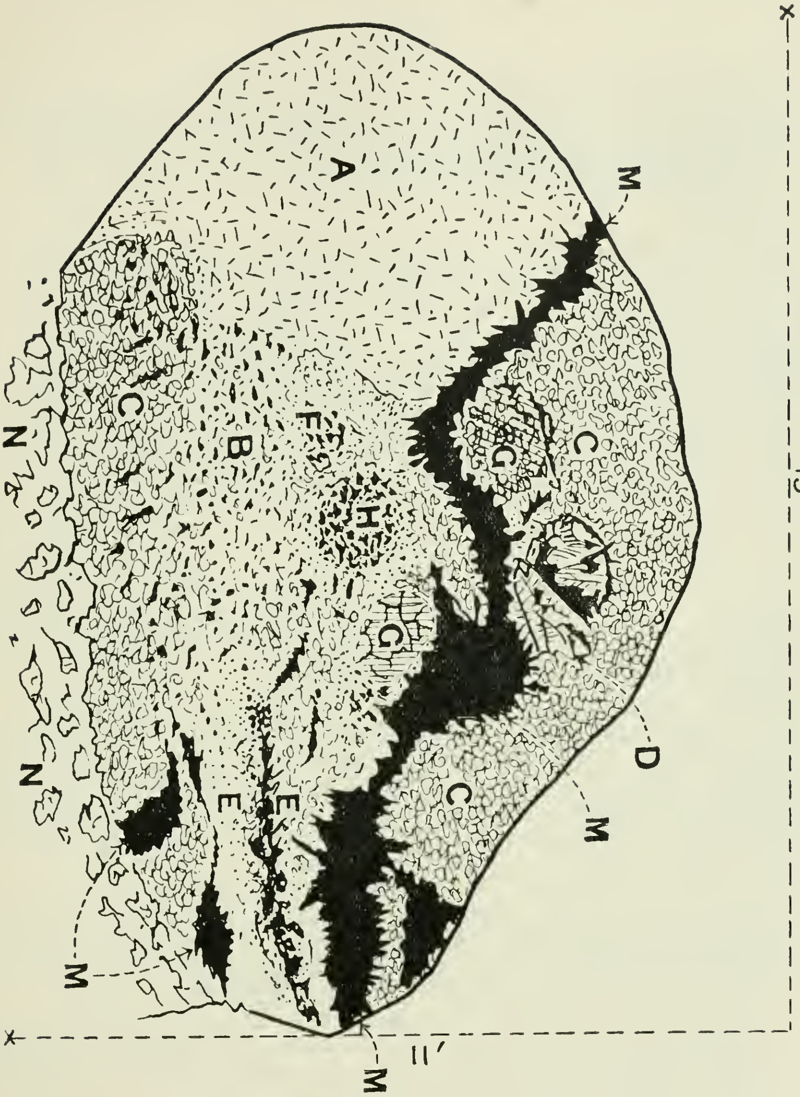
Ore and Gangue.—The ores are molybdenite and bismuth; wolfram, gold, and silver have also been found associated with the molybdenite and bismuth.* The gangue consists of quartz, secondary mica (sericite), calcite, and, at times, pyrites.

In this connection, also, we may mention the close association of a large "sandstone" granite dyke (see section), containing bands of tourmaline and pegmatite (graphic granite).

Origin of "Pipe."—After the granite had cooled, subsequently to its intrusion of the slates, and at the time when the "sandstone" granites intruded the coarser varieties, at points thousands of feet below the surface of that time, the water, which at one period of the intrusion was intimately mixed up with the liquid granite, was thrown off by the mass as it consolidated and journeyed outwards towards the cooler surrounding rocks. This water, owing to its great pressure, was as hot as the associated granites.† It also contained sulphuretted hydrogen and carbonic acid gases, besides, in all probability, a percentage of potash. Owing to the presence of these gases, and to their own intensely hot and compressed nature, these gradually coalescing waters could easily hold in solution such metal as molybdenite, tin, bismuth, tungsten, and gold, which they picked up in their passage through the cooling magmas. The line of contact was a weak place, and through the older coarse granite near this approximately plane surface the waters (or gases) forced their way upwards in tortuous passages. The original joint intersections (if any such existed) were of exceedingly small dimensions, *the bulk of the "pipes" now being merely replaced country!* To the close observer the steps in the process of replacement are evident. Firstly, the strong waters attacked the micas (biotites) and such rare hornblendes as might be present. Soft tufted aggregates of sericite (secondary mica) were the result of this process. Next a yellowish clouding of the felspars occurred, which developed gradually into masses of secondary tufted mica. Side by side with this process, and also as a still later stage in the alteration, came the development of granular quartz with the sericite, and the replacment, in turn, of *the sericite itself* by masses of hard granular black quartz. With this also the gradual replacement of felspars, &c., by flakes and tufts of molybdenite, occurred. The (see diagram) farthest stage of alteration was the development of *great masses of crystallised quartz, often bihexahedral,* and containing beautifully crystallised molybdenite throughout the quartz crystals. Between these large (often 3 ft. x 1 ft. x 1 ft.) quartz crystals occur great lenticular masses of molybdenite with smaller quantities of sulphide of bismuth, as also native bismuth. One of the large masses of molybdenite seen *in situ* by the author in 1902 must have exceeded 1 ton in weight. In the frontispiece are shown several masses of molybdenite torn from a single block and photographed by the author in 1902. The weights are respectively, 5 cwt., 6 cwt., and 80 lb.

* C. S. Wilkinson, Ann. Report, Dept. Mines, 1883, pp. 154–155. E. F. Pittman, Mineral Resources, N. Wales, p. 259.

† Or generally, as that of the pegmatite and eurite dykes associated with them.



Sketch Plan of Sachs' Molybdenite pipe, at present face 250 feet deep on underlay.

A. Coarse acid granite (country) showing seritization of felspars and development of flakes and scales of molybdenite.

B. Still more altered granite passing insensibly on all sides into tight granular quartz with flakes of molybdenite.

C. Hard granular quartz, showing traces of felspar, and considerable development of molybdenite.

D. Patch of quartz crystals, showing molybdenite and bismuth patches, both between and inside quartz.

E. White massive quartz developing from sericite.

F. Hard,tight, glassy quartz, developing from sericitised granite (A).

G. Massive quartz developing from hard granular cairngorm.

H. Granite, almost completely altered to sericite. The contours of the original felspars still showing.

M. Masses of molybdenite in large tables, foils and aggregates. (Bismuth associated with Mo S_2 as sulphide and native).

N. Broken ore.

NOTE.—This peculiar sericitisation and silicification of granite characterised the pipe all the way down ; also all the other Kingsgate pipes ; also the Timbarra and Pheasant Creek pipes.

Doubtless the origin of these huge masses of molybdenite and native bismuth is due, in part, to secondary concentration. The chemistry of this subject is, however, unknown to the author, who would suggest it as a problem well worth investigating.

The production of this mine since 1900 has been 80 tons of molybdenite.

Ore Dressing.—The ore is drawn to the mouth of the tunnel and there stacked. Hand-picking of the larger molybdenite (and bismuth) specimens is resorted to. The remainder is trucked to the ore-shoot, and there delivered to steel-rolls and jigs. The oversize from the jigs is again crushed between rolls, after hand-picking of the large flakes of molybdenite which had been separated from the quartz by the crushing. Treatment by Wilfley tables is then adopted, the overflow being paddocked. Most of the bismuth is saved, but a great loss of fine molybdenite is sustained. Possibly a modification of the Elmore process would obviate this. [Later.—A simpler and better form of concentration is now in practice.]

Other Kingsgate Properties.—Many other mines exist at Kingsgate, worked primarily for bismuth, and secondarily for molybdenite. Such are the numerous quartz "pipes" on Vickery's mineral conditional purchases. Doubtless, other "pipes" occur along the main granite and slate junction of this locality, especially where associated with miarolitic "sandstone" granite bosses and dykes, and of these some will, in all probability, be equally valuable as Sach's mine.

It might be profitable to add here, that prospecting for these "pipes" is not an easy task. The country is covered with such a dense waste-sheet (rain-wash) and thick vegetation, the outcrops of the "pipes" are so small and the minerals shed (bismuth and molybdenite) so susceptible to physical and chemical decay, as compared with tin and gold, that, except in such favourably-situated spots as rocky gorge sides, the location of the "pipe" outcrops is exceedingly difficult.

Warral Creek, near Macksville.—Shaft sunk 28 feet, reef 3 feet wide (shown), with good ore. A parcel of 3 cwt. was obtained, and disposed of for £20. It was proposed to sink for 50 feet, then open up reef. (Ann. Rept. Dept. Mines for 1904, p. 55.)

Specimens shown to the author by Mr. Robinson, of Drake, show the gangue to be quartz, with *large admixtures of felspar*, the whole being strikingly suggestive of a vein having pegmatitic affinities and associated with an acid granite boss.

Oban, County Clarke.—Molybdenite (Liversidge). (Quoted from E. F. Pittman.) Associated with "sandstone" granites traversing coarse acid granites. (E.C.A.)

Pheasant Creek, Parish Moogem, County Clive.—Molybdenite in quartz in pipe veins associated with wolfram and bismuth minerals. (Quoted from E. F. Pittman.) The principal geological features are a main coarse acid granite and porphyry junction, along which are arranged "pipes" of sericite (secondary mica) containing tinstone and allied minerals. (E.C.A.)

Tarana, County Roxburgh.—Molybdenite (Liversidge). (Quoted from E. F. Pittman.)

Tenterfield.—

(*a*) *Town Common*, 2 miles west of Post Office.—Occurrence: As flakes in tiny quartz veins (¼ in. to ½ in. wide) in large acid ("sandstone") granite dykes exceeding 5 chains in width, traversing blue granite.

The dyke has, in cooling, contracted normally to its length, and the resulting fissures have been filled with quartz containing molybdenite (*vide* diagram illustrating chapter on "Hints to Prospectors.")

(*b*) *Tenterfield Creek*, 1¼ miles south of post office. Occurrence: As flakes in an eurite dyke traversing alike the blue granite and sphene hornblendic granite-porphyry. This occurrence, as also that described in (*a*), is interesting, inasmuch as it proves the molybdenite to be a segregation of the granite dykes themselves. The molybdenite flakes occur in small lens-shaped pegmatitic secretions some 6 inches in length, shading off insensibly into the surrounding eurite. This type of dyke evidently represents a fairly well-hydrated magmatic excretion.

County Wellesley.—Molybdenite.

Wilson's Downfall, in a cutting along main road from Wilson's Downfall to Stanthorpe, ¾-mile from first-named township.—Occurrence: As a great number of scales and small flakes of molybdenite *scattered throughout* a miarolitic eurite dyke. The dyke is about 100 yards wide, and has its micas (biotite) in irregularly scattered plates (similar to mica in graphic granite). The association of the molybdenite with the peculiar miaroles shows it to be part of the intruding body which has cooled out in isolated patches, the hydration not being pronounced enough to allow of the concentration of the mineral in quartz veins.

The "sandstone" granite containing this molybdenite deposit intrudes the coarse porphyritic granite of Wilson's Downfall. This latter is an unique rock type, and contains innumerable patches of tin greisen; also wolfram. The later "sandstone" granite occurs as bosses from 2 to 3 miles in diameter, with net-works of dykes radiating therefrom.

Sydney: William Applegate Gullick, Government Printer.—1906.